Thermal Vacuum Testing of a Multi-Evaporator Miniature Loop Heat Pipe

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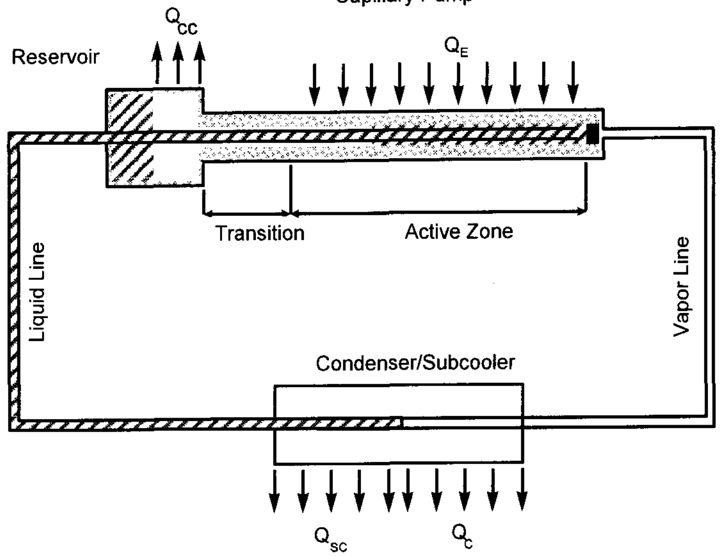
Outline

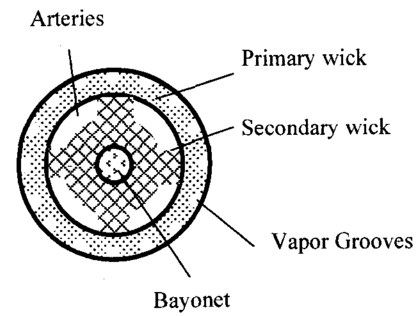
- Introduction/Background
- Test Article
- Thermal Vacuum Test Set-up
- Tests Performed
- Experimental Results
- Summary and Conclusion

Introduction/Background

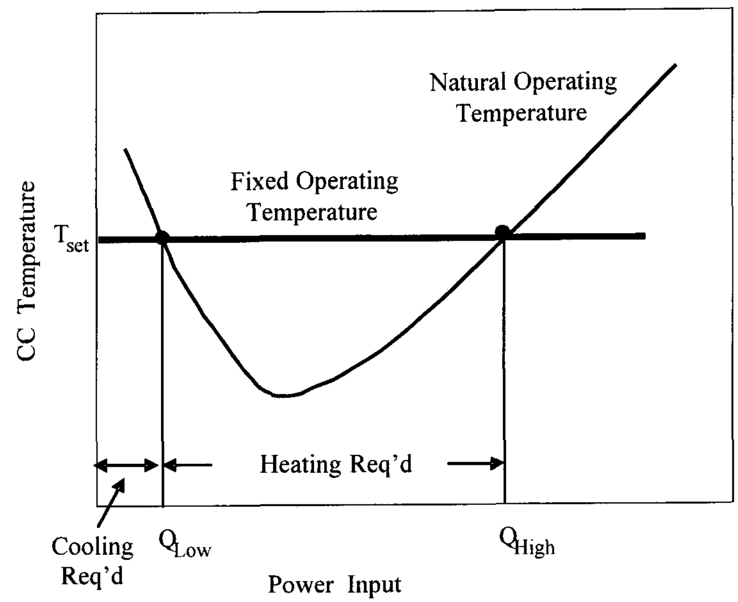
- Under NASA's New Millennium Program Space Technology 8 Project, four experiments are being developed for future small system applications requiring low mass, low power, and compactness.
- GSFC is responsible for developing the Thermal Loop experiment, which is an advanced thermal control system consisting of a miniature loop heat pipe (MLHP) with multiple evaporators and condensers.
- The objective is to validate the operation of an MLHP, including reliable start-ups, steady operation, heat load sharing, and tight temperature control over the range of 273K to 308K.
- An MLHP Breadboard has been built and tested for 1200 hours under the laboratory environment and 500 hours in a thermal vacuum chamber.
- Results of the TV tests are presented here.

LHP Basics





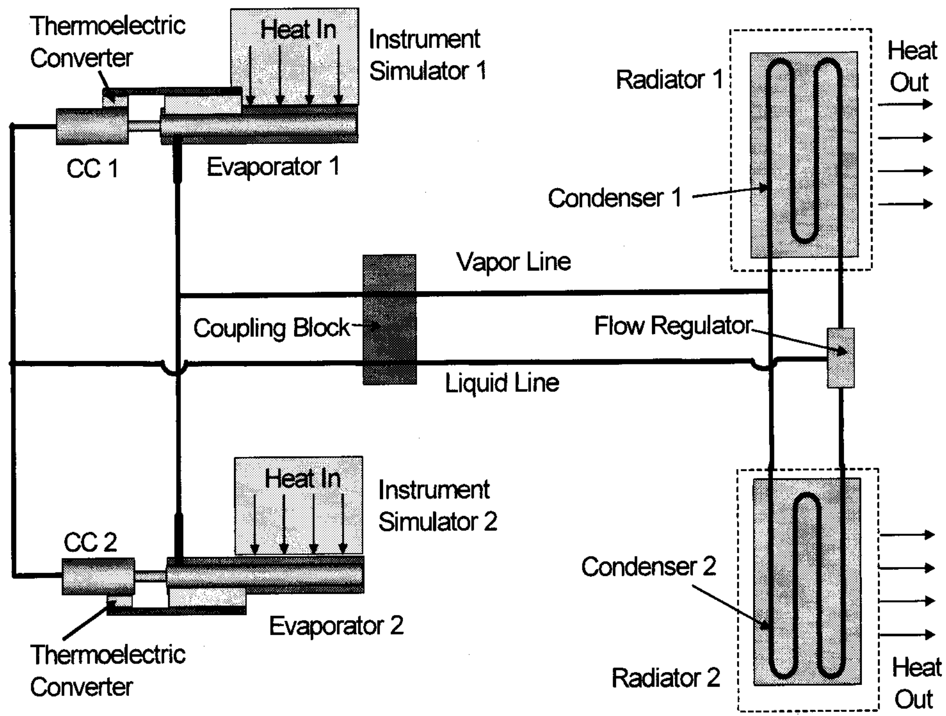
Cross Sectional View of Evaporator Core



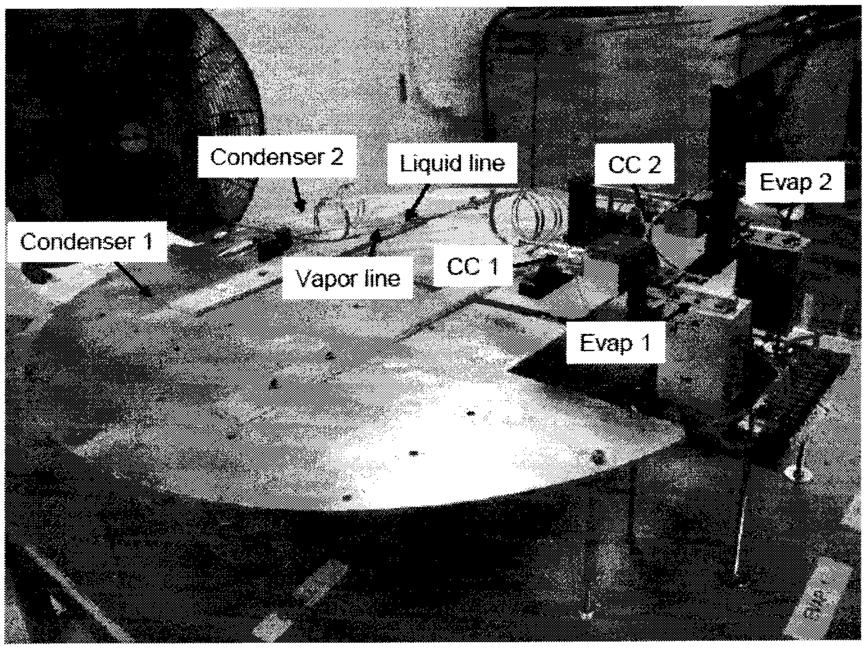
- **No external pumping power and no moving parts**
- **Passive and self-regulating**
- **Operating temperature can be controlled at the desired set point**
- **State-of-the-art**
  - **Singe evaporator**
  - **1 inch (25.4mm) wick**
  - **Heating the CC only, no active cooling**

Thermal Loop Concept Description

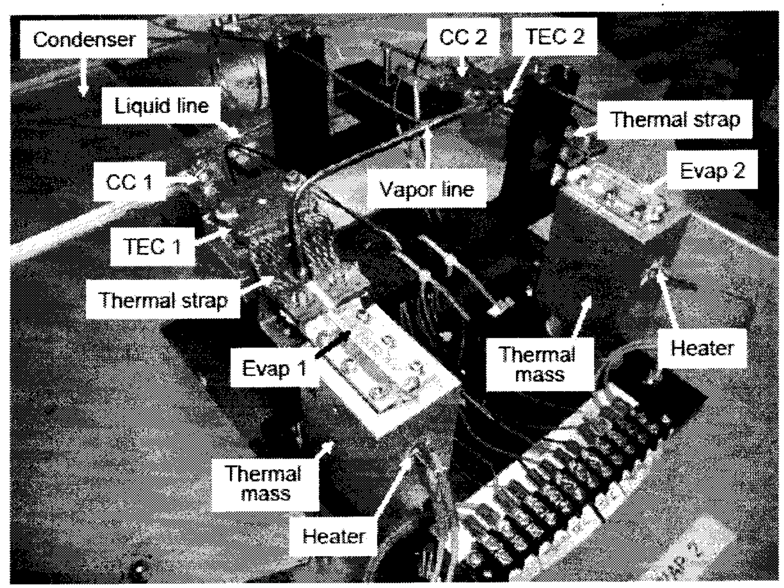
- **Miniature Loop Heat Pipe**
  - Two parallel evaporators
  - Two parallel condensers
  - Compensation chambers (CC)
    - Fluid reservoir
  - Flow Regulator
    - Prevents vapor blow through when only one condenser is fully utilized
  - Working Fluid
    - Anhydrous ammonia
- **Instrument Simulators**
  - Simulate instruments or electronic box
- **Thermoelectric Converters (TECs)**
  - Maintain CC saturation temperature
  - Variable set point control
- **Coupling Blocks**
  - Reduce control heater power requirements by transferring heat from vapor to return liquid



Pictures of MLHP Breadboard 2

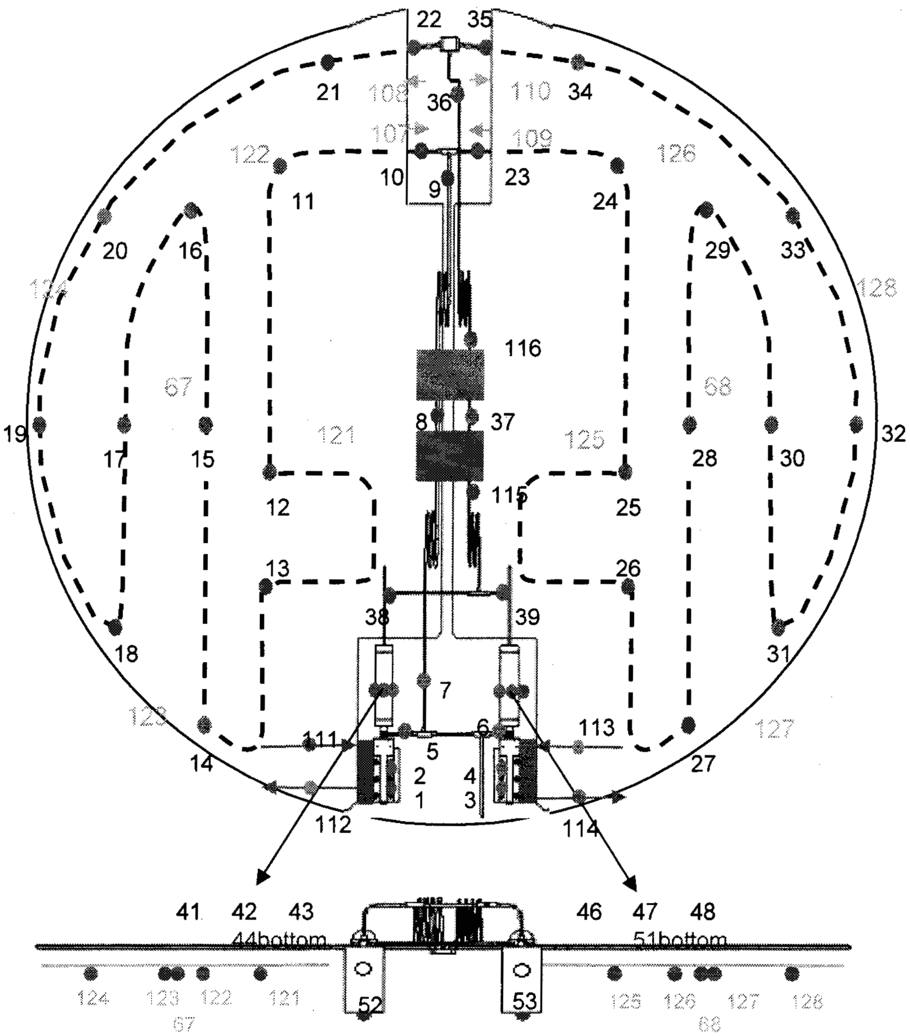


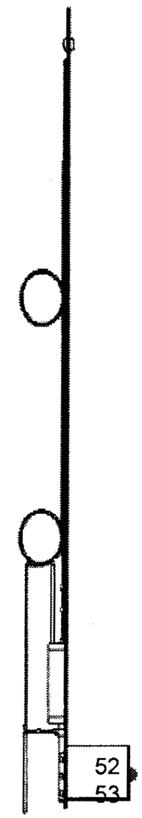
Overall View



Close View of Evaporator/CC Section

ST8 Breadboard 2 – TC Locations





Test Setup and Instrumentation

- Each evaporator has a 400-gram aluminum mass attached.
- A cartridge heater was inserted into each thermal mass to provide 1W to 150W of heat load.
- A cooling block was attached to each thermal mass to provide a heat sink for heat load sharing tests. The coolant temperature and flow rate were varied during the test.
- A thermoelectric converter (TEC) was attached to each CC. The other side of the TEC was connected to the evaporator through a copper strap.
- Each TEC was connected to a separate bi-polar power supply.
- More than 100 type T thermocouples were used.
- Data acquisition system
  - Two dataloggers
  - Two PCs
  - Collect, display, and store data every second.
- Labview software was used for command and control of test conditions.

Problem Encountered During Testing

- A problems with the test set-up led to sporadic data drops.
  - Each time this happened, all temperatures read 282K for a single data scan.
  - The TECs responded to this erroneous reading, changing the saturation temperature.
  - As a result, the CC temperature fluctuated about 1K for a few minutes until stable temperatures were reestablished.

- In spite of this problem, the TECs demonstrated their abilities to bring the CC temperature quickly to the desired set point temperature.

Tests Performed

- Start-up
- Operating Temperature Control
  - TECs and electrical heaters
  - Power cycle
  - Sink temperature cycle
  - CC temperature change
- Heat Load Sharing
- Flow Regulator Function
- TEC Power Savings
  - Effects of Coupling Blocks on CC Control Heat Power
- Demonstrated more than 500 hours of LHP operation under a wide range of operating conditions in a thermal vacuum environment.

Start-up Tests

- **51 start-up tests were conducted. All were successful.**
  - **Start-up was indicated by the rise of the vapor line temperature and the drop of the liquid line temperature.**

- **CC temperature: 0, 1 or both CCs were controlled between 258K and 308K**

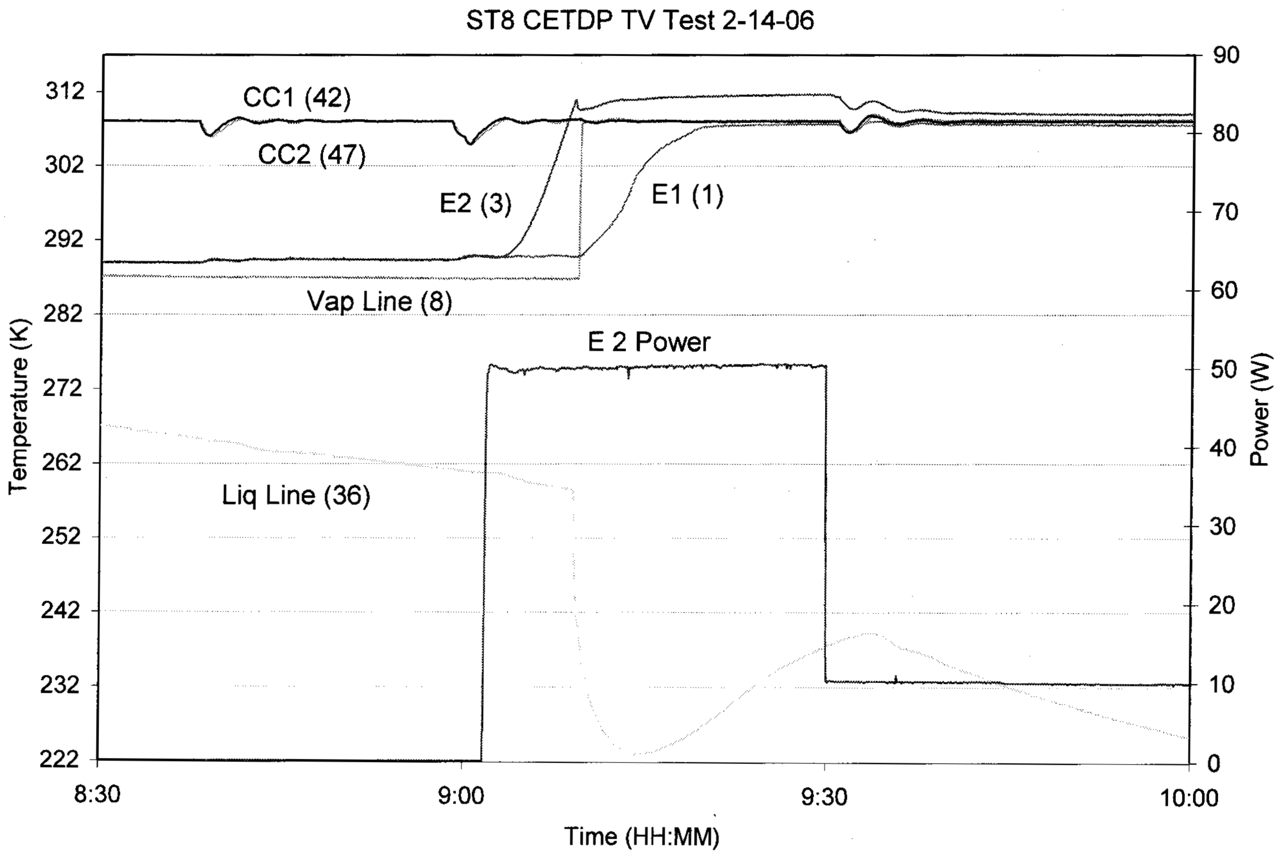
- **A heat load of 5W to 50W was applied to one evaporator, independent of the heat load to the other evaporator, i.e. even and uneven heat loads**

- **Temperatures of the two condenser sinks varied between 203K and 273K, independent of each other**

Start-up

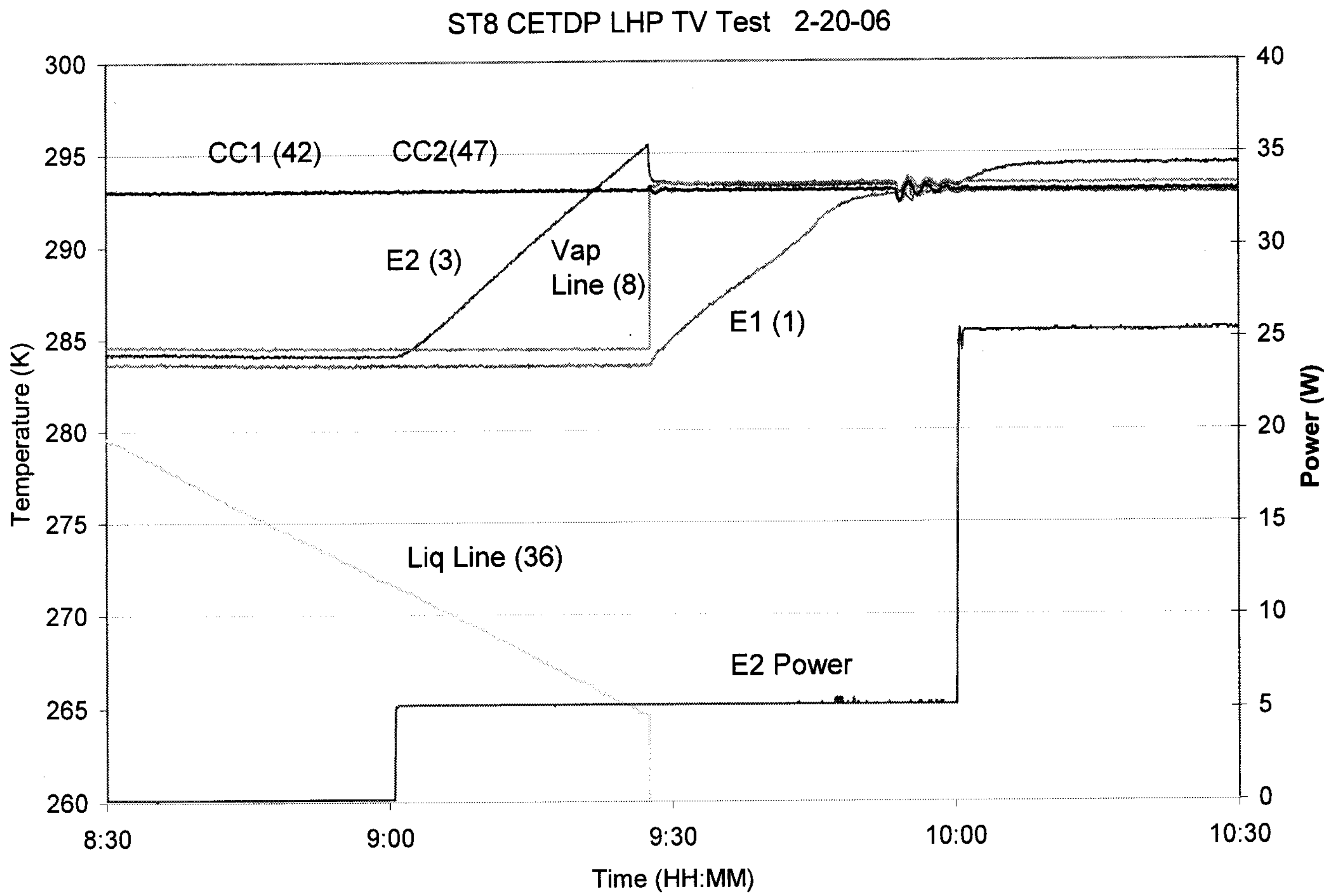
308K/308K, 0W/50W

- **With 50W to E2, Mass2 and E2 temperature reached the set point quickly.**
- **E1 began to share heat after loop started.**



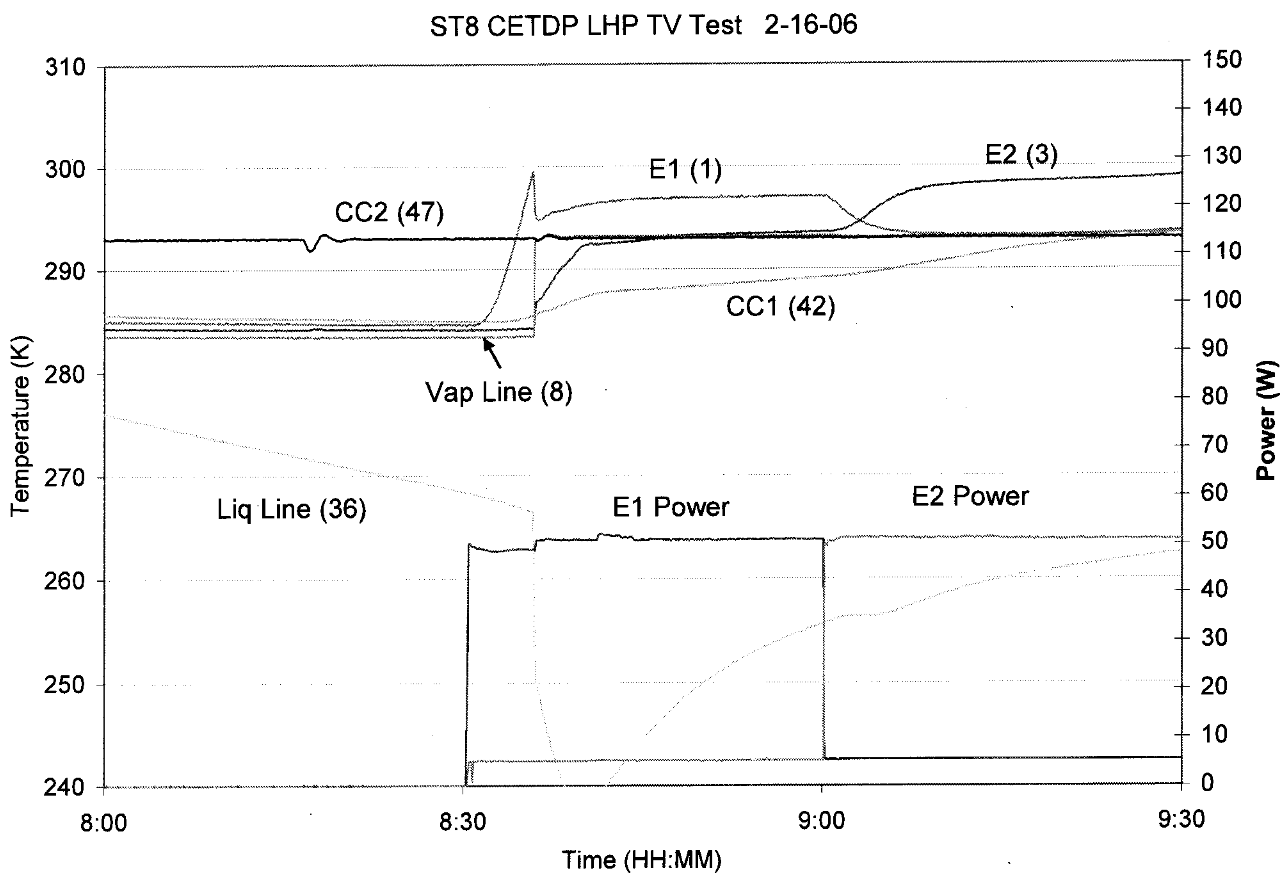
Start-up
293K/293K, 0W/5W

- **2.5K superheat on E2 at start-up**
- **E1 shared heat after loop started.**



Start-up
No control/293K, 50W/5W

- **E1 was flooded prior to start-up.**
- **E1 reached set point temperature first and started the loop with 7K superheat.**



Saturation Temperature Control

- The loop operating temperature could be controlled by controlling the temperature of one or both CCs.

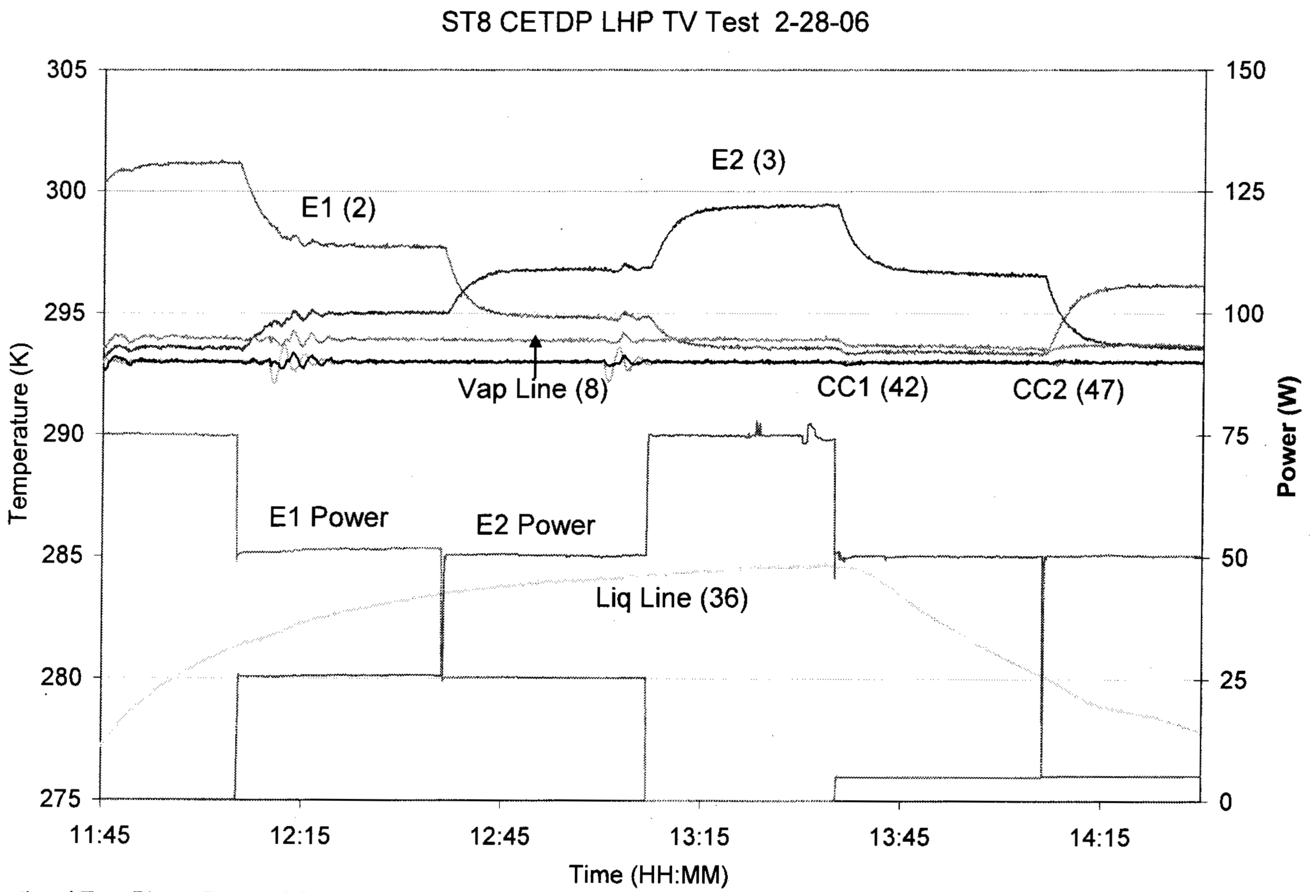
- The loop operating temperature could be controlled within $\pm$0.5K using TECs or electrical heaters.

- The loop operating temperature could be changed while the loop was operating.

- Using TECs, the loop operating temperature could be controlled below the ambient temperature and below the loop's natural operating temperature.

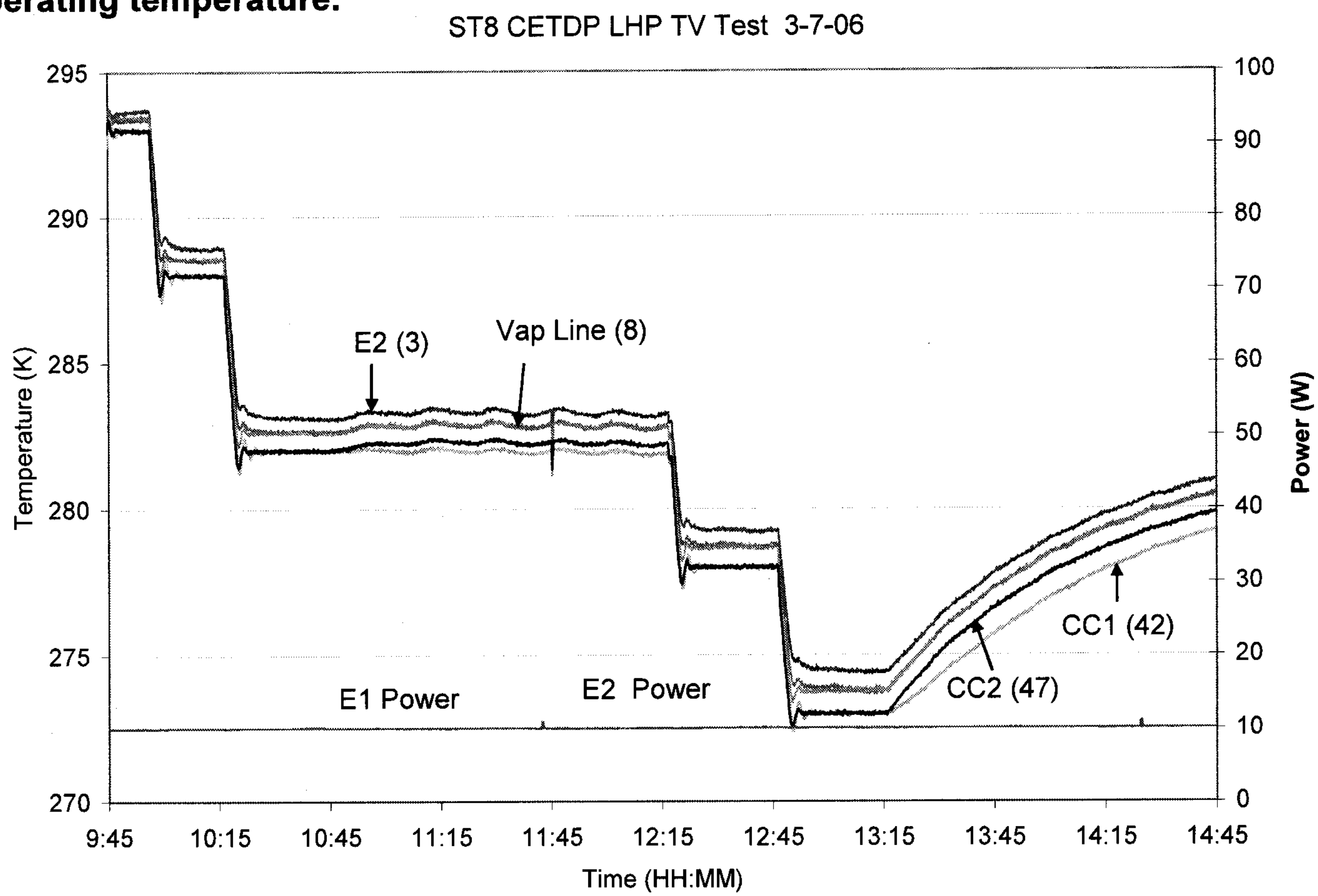
Power Cycle

- **CC1/CC2= 293K/293K, C1/C2 sink = 173K/173K**
- **E1/E2 power = 75W/0W, 50W/25W, 25W/50W, 0W/75W, 5W/50W, 50W/5W**
- **The loop operating temperature was maintained within ±0.5K of the 298K set point temperature.**



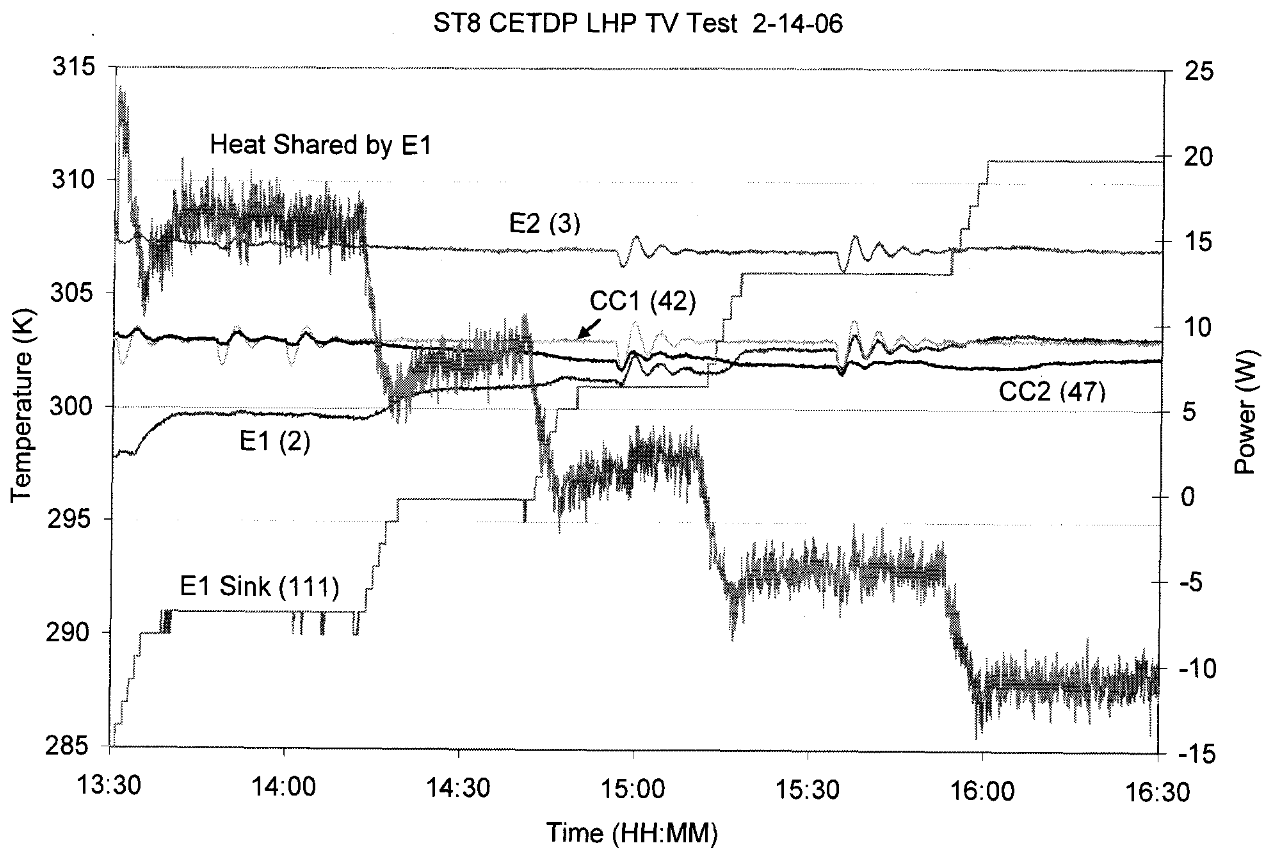
CC Set Point Change

- C1/C2 sink = 223K/223K. E1/E2 power = 10W/10W.
- CC1/CC2=293K/293K, 288K/288K, 283K/283K, 278K/278K, 273K/273K, NC/NC
- TECs enabled CC1/CC2 to control the loop saturation temperature below its natural operating temperature.



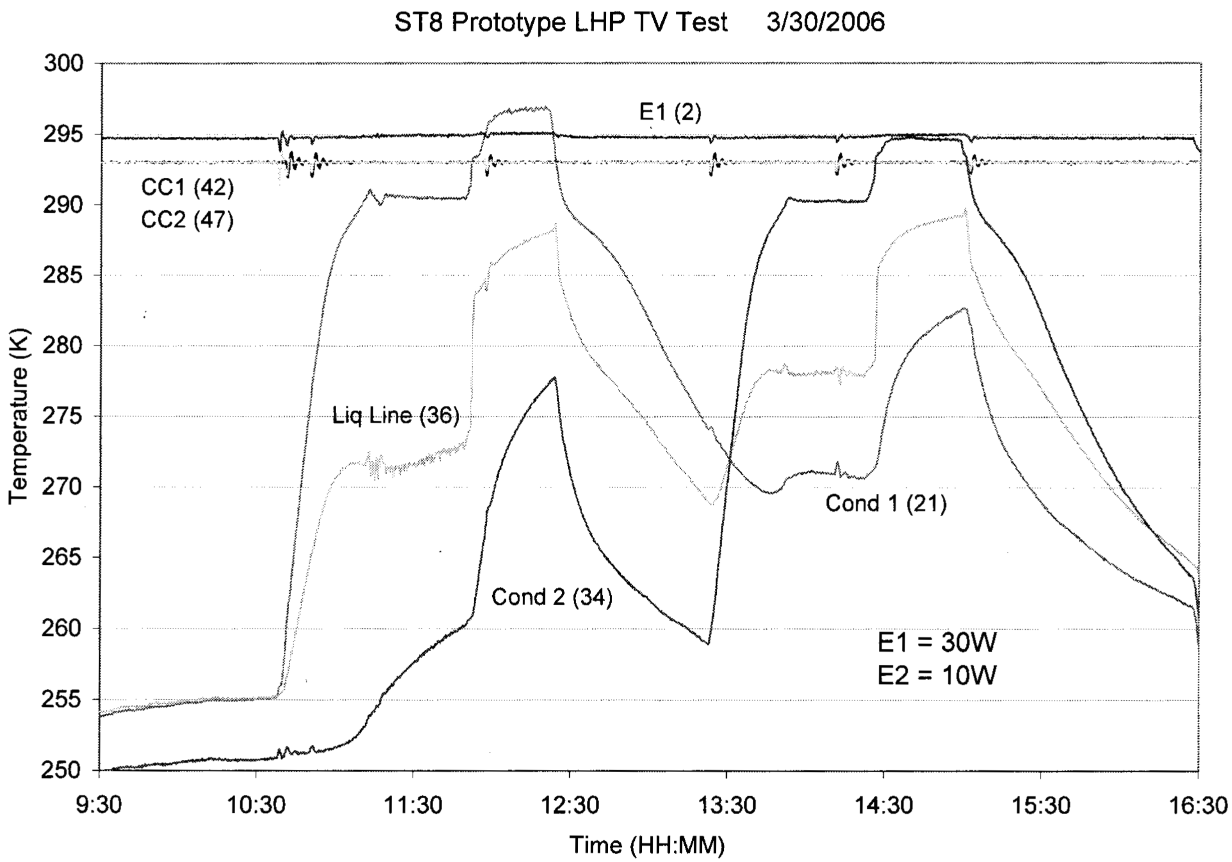
Heat Load Sharing

- **CC1/CC2 = 303K/NC, E2 power = 50W constant, C1/C2 sink = 203K/243K**
- **E1 coolant flow rate = 0.15 gpm**
- **E1 coolant temperature = 283K/288K/293K/298K/303K/308K**
- **As coolant temperature reached 303K and 308K, E1 received heat from the coolant and was in its normal operation (shared negative heat)**



Flow Regulator Test

- E1/E2 power = 30W/10W constant. CC1/CC2 = 293K/293K
- C1/C2 sink = 223K/223K, 293K/223K, 298K/223K, 223K/223K, 223K/293K, 223K/298K, 223K/223K
- Both sides of the flow regulator worked properly to stop vapor.

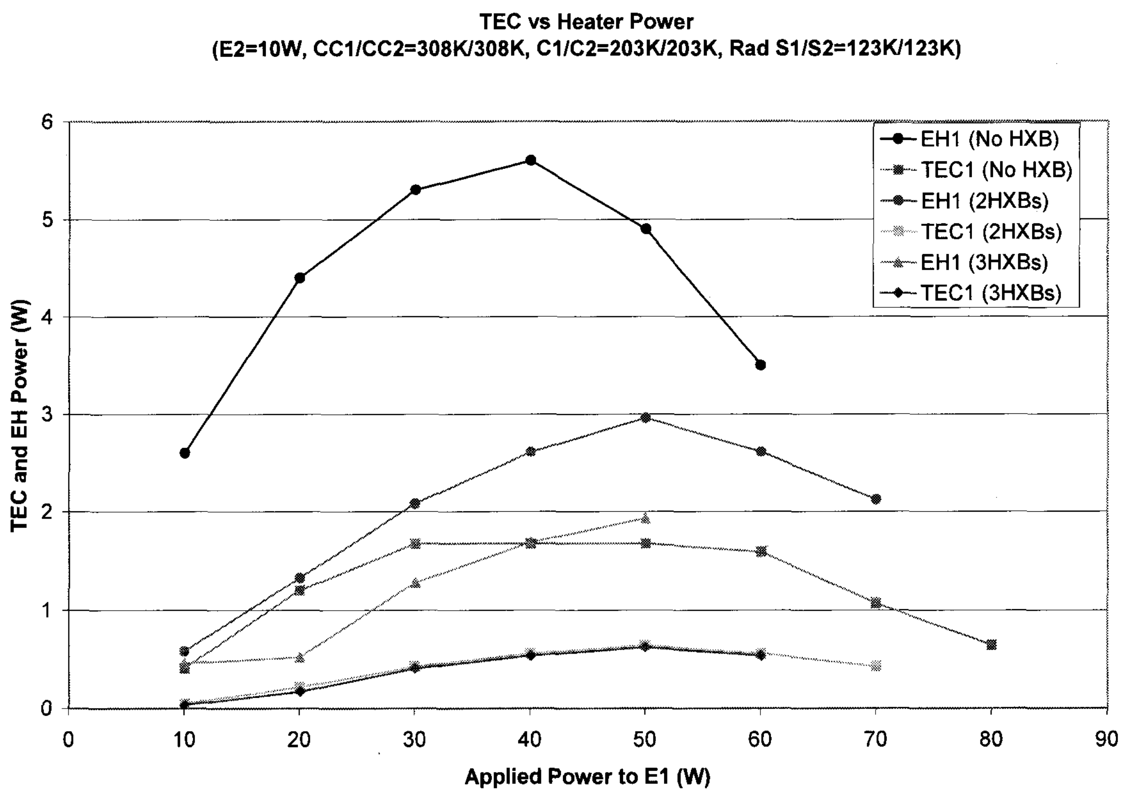


TEC Power Savings Test

- Thermal Loop design incorporates coupling blocks and TECS to reduce control heater power requirements. Test were conducted using electrical heaters and TECs.
  - Quantify amount of power savings
- Power to E1/E2: 10W/10W, 20W/10W, 30W/10W, 40W/10W, 50W/10W, 60W/10W, 70W/10W.
- CC1/CC2 set point: 308K(EH)/308K(TEC), 308K(TEC)/308K(TEC)
- Number of coupling blocks: 0, 2 and 3.
  - Affects temperature of returning liquid
  - Affects control heater power requirement

TEC Power versus Electrical Power

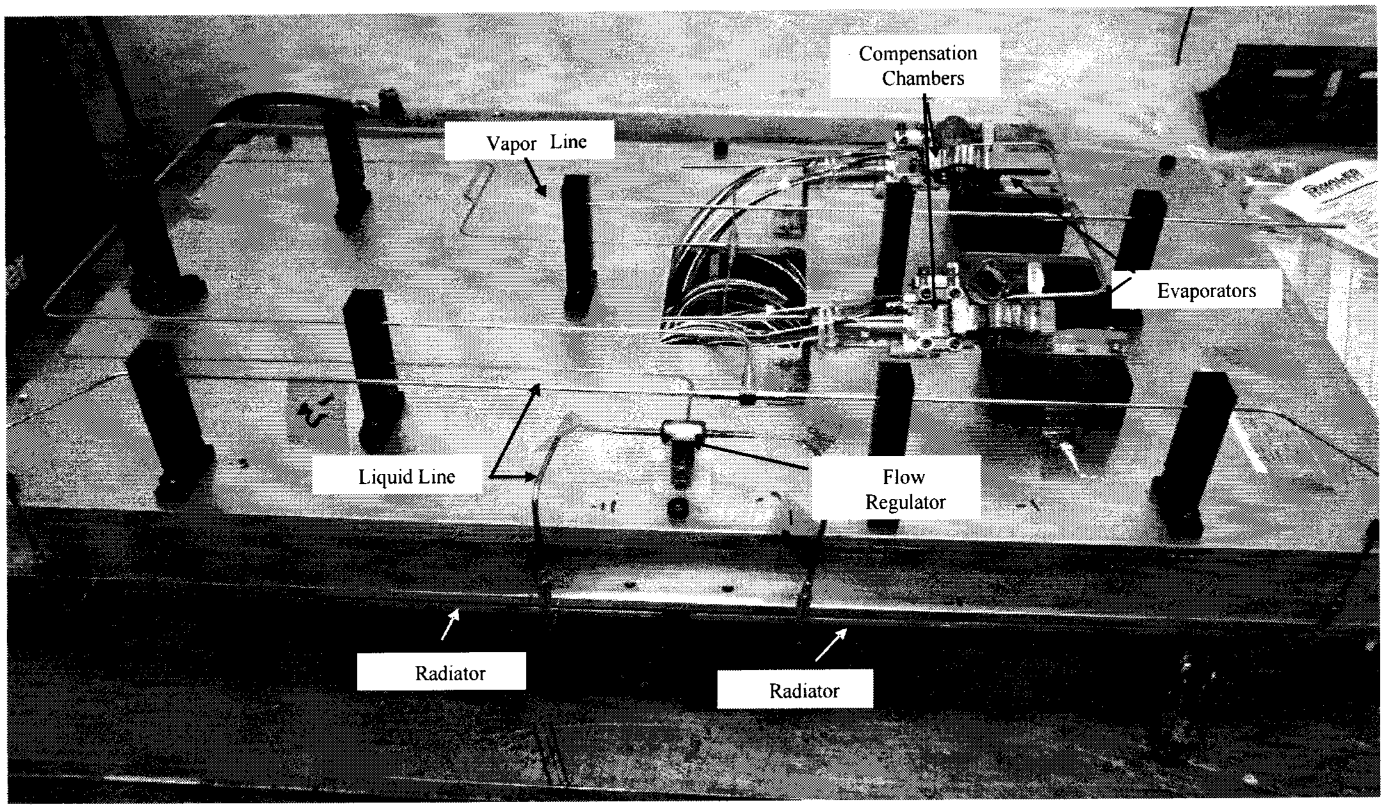
- TECs reduced control heater power by more than 60% compared to electrical heaters.
- Coupling blocks were also effective in reducing the control heater power.
- Combination of coupling blocks and TECs yielded significant power savings.
- Ambient tests under various sink temperatures and 0, 2, 3, 4 blocks showed similar power savings.



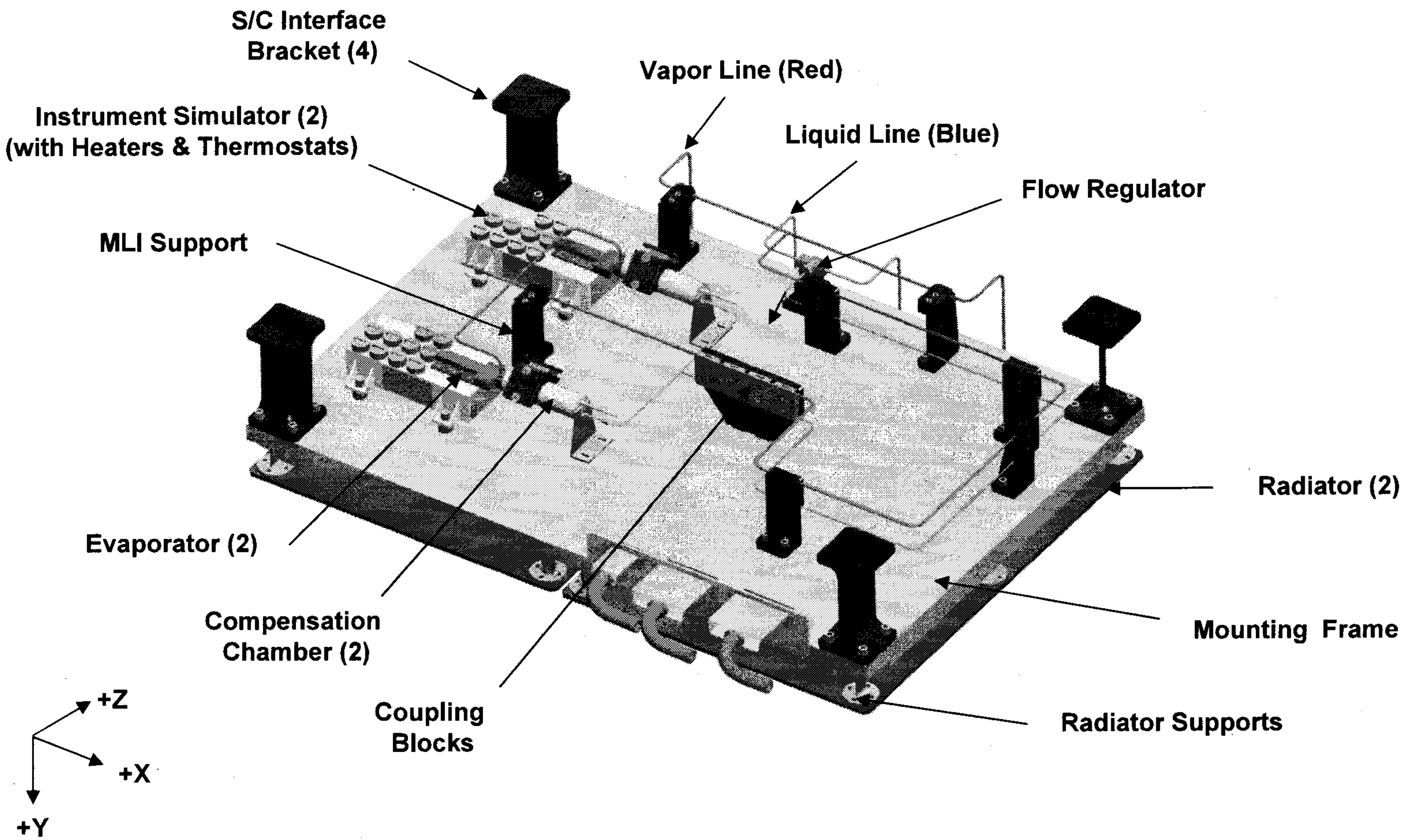
Summary

- The MLHP demonstrated more than 500 hours of operation under a wide range of operating conditions in a thermal vacuum chamber.
- One hundred percent success rate of start-up: turn-key start-up with TECs.
  - CC temperature: 0, 1 or both CCs were controlled between 258K and 308K
  - Heat load between 5W and 50W to either one evaporator independently
- Operation
  - The LHP operating temperature was controlled within ±0.5K of the desired set point
  - Stable LHP operation at all times over the full range of heat loads and sink temperatures
  - Demonstrated heat load sharing between the two evaporators
- TEC for temperature control
  - Provided both heating and cooling
  - The loop operated below natural operating temperature
  - Saved control heater power by > 50% compared to electric heaters

Protoflight MLHP for TRL 6 and TRL 7 Validation



MLHP Module Concept for TRL 7 Validation
(view from Spacecraft)



Thermal Loop Capabilities

- Turn-key start-up using TECs
- Fine temperature control at any temperature between 273K and 308K
- Control temperature can be varied while operating.
- Thermal bus for multiple instruments or heat dissipating locations
  - Any power distribution between two heat sources up to the maximum total load, including negative loads (heat load sharing) for one load.
- 100W+ heat transport limit
- Heat dissipation to radiators exposed to different thermal environments.
  - Will continue to operate as long as one radiator can dissipate entire load, even if other radiator has a net heat gain.

QUESTIONS?